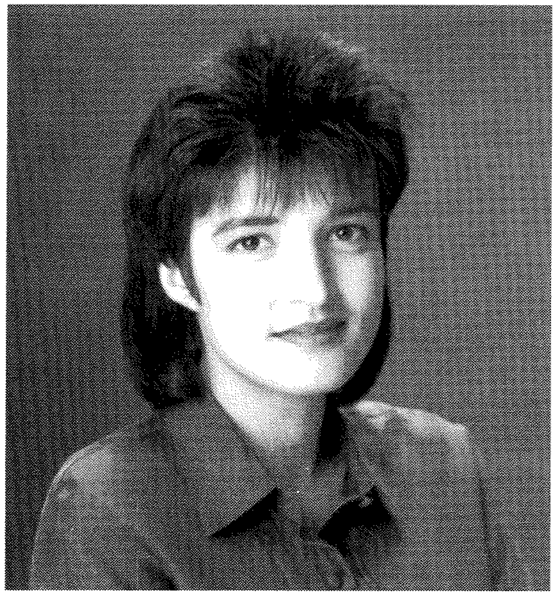

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D. CASEY KERRIGAN, MD, MS, is Associate Professor and Director of Research at Harvard Medical School's Department of Physical Medicine and Rehabilitation (PM&R) and Founder and Director of the Center for Rehabilitation Science at Spaulding Rehabilitation Hospital, Boston, MA. She received her medical degree from Harvard Medical School and her residency training in PM&R from Cedars-Sinai Medical Center, West Los Angeles VA Medical Center, Children's Hospital of Los Angeles, Rancho Los Amigos Medical Center, and the University of California at Los Angeles, where she also received a Master's degree in kinesiology. She developed and directs the clinical and research Gait Laboratory at Spaulding Rehabilitation Hospital. Dr. Kerrigan also created the initial curriculum for the PM&R Residency Program at Harvard Medical School and served as its program director from 1994 to 1995. She was appointed a member of the committee to establish the Department of Energy/National Institutes of Health Lower Limb Prosthetics Project, where she served from 1996 to 1997. She is a founding member of the American Gait Laboratory Accreditation Board, which was established in 1995.

Among Dr. Kerrigan's many awards are the Ralph Goldman Intern of the Year Award from the West Los Angeles VA Medical Center (1988); the Outstanding Service Award for Resident Physician Council from the American Academy of PM&R (1992); the Young Academician Award from the Association of Academic Physiatrists (1996); and the First Special Recognition Award for Outstanding Teaching in the Harvard Medical School PM&R Residency Program (1996). She has published extensively in the area of gait and holds several foundation grants and a Clinical Investigator Award from the National Center for Medical Rehabilitation Research at the National Institutes of Health. Dr. Kerrigan is the recipient of grants from several foundations, the National Institutes of Health, and the Department of Veterans Affairs, all related to the subject of gait.

INTRODUCTION/PROLOGUE

by D. Casey Kerrigan, MD, MS

Modern-day quantitative gait analysis, including kinematic or joint motion measurement, kinetic or joint torque assessment, and dynamic electromyographic (EMG) recording, is one of the few, if not the only, measurement systems that quantify functional limitation, along with impairment and disability. Clearly, quantitative gait analysis allows an objective evaluation of the effectiveness of various rehabilitation treatments aimed at improving gait disability. For instance, quantitative gait analysis, as a functional assessment tool, has been used to show the benefits of various orthopedic surgical procedures and rhizotomy techniques in persons with neurological impairment. It has also been used to assess the biomechanical effects of bracing, prosthetic components, and other rehabilitative modalities.

However, functional assessment, or outcome measurement, is but one small role that quantitative gait analysis can play in the science of rehabilitation. If we expand the definition of gait analysis to include *interpreting* the significance of quantitative gait data, then the most promising aspect of gait analysis is that ultimately we will understand the complex relationships between impairment, functional limitation, and gait disability. An understanding of these relationships should vastly improve our rehabilitation treatment strategies.

The use of quantitative gait analysis in the rehabilitation setting has increased only recently. Gait analysis methodology has been around for over 100 years; however, work to improve gait analysis technology and repeatability has occurred only over the past 10 years. Often in the past, the technical details of gait analysis made *clinical* gait analysis extremely cumbersome and time-consuming. Two major factors made the routine use of gait analysis impractical, particularly in individuals with poor walking ability. The first factor was the time and effort required for setting up and testing a subject and the associated burden to that person. Depending on a particular protocol, obtaining kinematics with video capture could require that the individual not use an assistive device or that he or she walk with his or her arms crossed. The apparatus attached to the person was frequently heavy and constricted joint movement. The second major limitation was the time and effort required to process and analyze the data. Also, unreliability of data acquisition and processing methods required an inordinate number of trials, burdening both the people being tested and the staff. Such limitations undoubtedly prohibited gait analysis on a regular clinical basis.

There is a growing acceptance of the clinical use of gait analysis in the rehabilitation setting. Fortunately, in recent years many technical difficulties have been overcome. Recent advances, such as improved computer processing and the development of passive as opposed to active marker systems, have enabled the faster acquisition of kinematic data without heavy encumbering attachments and wires trailing from the subject. Also, with improved computer integration and software, kinetic data are more automatically obtained from a combination of kinematic and force plate data. Although once impractical, a modern-day gait laboratory can now allow for routine assessment of gait in standard rehabilitation settings.

Currently, the most common clinical use of gait analysis is the assessment of spastic paretic gait. Analysis allows us to understand the dynamic implications of a particular impairment, such as spasticity or weakness, in a particular muscle group. For instance, in some individuals, spastic paretic stiff-legged gait, defined as reduced knee flexion during the swing period of the gait cycle, may be the result of quadricep spasticity. In fact, a standard, static evaluation may reveal spasticity in the quadriceps. A gait analysis, however, may or may not demonstrate inappropriate activity in the quadriceps during the critical phases of the gait cycle when the knee should be flexing in preparation for and during swing. In this way, gait analysis allows us to determine the functional implication of an impairment. In some cases, by using gait analysis we may observe an impairment or functional limitation that is not at all appreciable with static evaluation. For instance, despite normal tone and the absence of spasticity in a particular muscle group such as the quadriceps, gait analysis may reveal inappropriate activity in that same muscle group.

With gait analysis, we have the potential to determine those impairments and functional limitations that probably contribute to the walking disability. Although a gait disability may be phenotypically similar from one individual to another, the impairments are typically distinct between individuals. Probably no two sets of quantitative gait data from two individuals are the same, no matter how visually similar their gait disability appears. Logically, the optimal treatment for a given individual will be the one that addresses the impairments and functional limitations that are most likely contributing to the walking disability. Gait analysis should provide this information, thereby allowing an effective rehabilitation management program. That gait analysis can help define the appropriateness of a number of rehabilitative modalities is probably its most important potential contribution to rehabilitation science.

By defining the causative impairments and functional limitations, a gait analysis can be used to focus and optimize rehabilitation treatment including the prescription, for instance, of specific strengthening or stretching exercises, EMG biofeedback, functional electrical stimulation, orthotics, or nerve or intramuscular neurolytic blocks. A quantitative gait evaluation may identify which muscles are firing appropriately and which are not, based on the kinematics, dynamic EMG, and kinetics. Gait analysis especially fills a void in upper motor neuron pathology, where traditional static evaluation measures are not effective in measuring either muscle strength or spasticity, at least from a functional standpoint. By providing information as to which muscle groups need strengthening (or electrical stimulation, or bracing), and which need relaxation (or stretching or intramuscular neurolysis), gait analysis can lead to a more optimal, methodical, and directed rehabilitation protocol.

By helping to pinpoint the causative impairments and functional limitations, gait analysis could be quite useful in optimizing experimental protocols involving a number of rehabilitation treatments. For instance, an experimental EMG biofeedback or functional electrical stimulation experimental protocol that was based on information obtained from quantitative gait analysis undoubtedly would be more likely to be successful than one that was not. Similarly, a program to test therapeutic modalities aimed at reducing spasticity would be more likely to be effective if it were based on information obtained from quantitative gait analysis. For example, a program to reduce tone in the quadriceps to improve stiff-legged gait would be functionally helpful only if gait analysis revealed that the quadriceps really were inappropriately active during gait. Gait analysis is thus potentially quite useful in optimizing, and thereby increasing, the likelihood of demonstrating the general effectiveness of a number of innovative, as well as standard, rehabilitation treatments. Of course, quantitative gait analysis, by providing objective functional assessment information, also can be helpful in assessing the outcomes of these specific rehabilitation programs.

The future of gait analysis in the science of rehabilitation is bright. Undoubtedly, its technology will continue to improve with new developments in computer vision, artificial intelligence, computational methods, and computer power. In addition, the models used to interpret gait analysis data will be refined and standardized. Perhaps the most exciting area of development is that of forward dynamic or robotic modeling, in which much work has already been done. Ultimately, we ought to be able to input kinetics that are measured with current gait analysis technology into a computerized robotic model. Inputting an individual's measured kinetics into the robotic model would result in a kinematic gait pattern that is similar to the individual's actual kinematic pattern. Then, we could predict the effect of changing the kinetic inputs; changing them in the robotic model would be the equivalent in the actual individual to some rehabilitation treatment that would alter an impairment, such as strengthening a particular muscle. We would be able to alter kinetic inputs in the model and observe the "would be" kinematic pattern changes. The ability to model and predict the effect of a treatment would not only provide a better understanding of the mechanisms of various gait disabilities, it would allow each person more precise individualized rehabilitation prescriptions for treatment.

With improved measurement techniques, gait analysis will continue to provide us with a better understanding of biomechanical and neurophysiologic function, both normal and abnormal, which may transcend to other activities of daily living. The role of gait analysis in the science of rehabilitation is much larger than simply a functional assessment tool as it can help us determine the complex relationships between impairment, functional limitation and disability. By defining these relationships, we not only will be able to design more optimal studies of the general effectiveness of a number of current rehabilitation treatment strategies, but will also be in a better position to consider new rehabilitation treatment strategies.